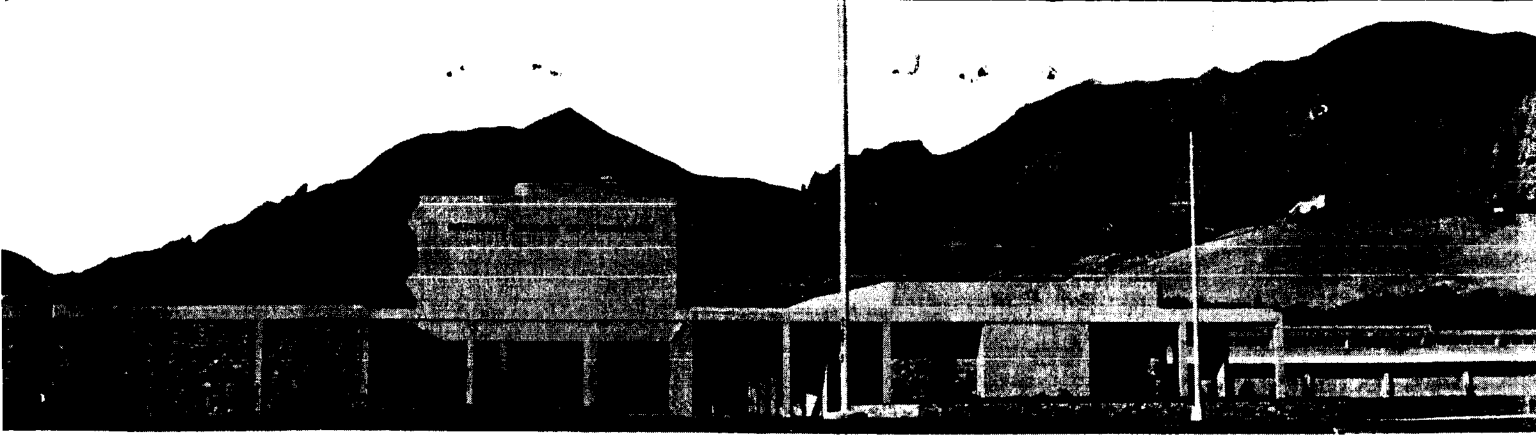

NBS REPORT

9261

R-45

TWENTY-THIRD PROGRESS REPORT

to

National Aeronautics and Space Administration

on

Cryogenic Research and Development

for

Period Ending September 30, 1966

NBS

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

BOULDER LABORATORIES

Boulder, Colorado

THE NATIONAL BUREAU OF STANDARDS

The National Bureau of Standards is a principal focal point in the Federal Government for assuring maximum application of the physical and engineering sciences to the advancement of technology in industry and commerce. Its responsibilities include development and maintenance of the national standards of measurement, and the provisions of means for making measurements consistent with those standards; determination of physical constants and properties of materials; development of methods for testing materials, mechanisms, and structures, and making such tests as may be necessary, particularly for government agencies; cooperation in the establishment of standard practices for incorporation in codes and specifications; advisory service to government agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; assistance to industry, business, and consumers in the development and acceptance of commercial standards and simplified trade practice recommendations; administration of programs in cooperation with United States business groups and standards organizations for the development of international standards of practice; and maintenance of a clearinghouse for the collection and dissemination of scientific, technical, and engineering information. The scope of the Bureau's activities is suggested in the following listing of its four Institutes and their organizational units.

Institute for Basic Standards. Applied Mathematics. Electricity. Metrology. Mechanics. Heat. Atomic Physics. Physical Chemistry. Laboratory Astrophysics.* Radiation Physics. Radio Standards Laboratory:* Radio Standards Physics; Radio Standards Engineering. Office of Standard Reference Data.

Institute for Materials Research. Analytical Chemistry. Polymers. Metallurgy. Inorganic Materials. Reactor Radiations. Cryogenics.* Materials Evaluation Laboratory. Office of Standard Reference Materials.

Institute for Applied Technology. Building Research. Information Technology. Performance Test Development. Electronic Instrumentation. Textile and Apparel Technology Center. Technical Analysis. Office of Weights and Measures. Office of Engineering Standards. Office of Invention and Innovation. Office of Technical Resources. Clearinghouse for Federal Scientific and Technical Information.**

Central Radio Propagation Laboratory.* Ionospheric Telecommunications. Tropospheric Telecommunications. Space Environment Forecasting. Aeronomy.

---

* Located at Boulder, Colorado 80301.

** Located at 5285 Port Royal Road, Springfield, Virginia 22171.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT		NBS REPORT
31500 - 3150400	September 30, 1966	9261
31503 - 3150430		
31504 - 3150440		
31505 - 3150450		
31505 - 3150451		
31506 - 3150460		
31507 - 3150470		

TWENTY-THIRD PROGRESS REPORT

to

National Aeronautics and Space Administration

on

Cryogenic Research and Development

for

Period Ending September 30, 1966

Cryogenics Division
Institute for Materials Research
National Bureau of Standards
Boulder, Colorado

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

TABLE OF CONTENTS

				Page
1.	Physical Properties of Cryogenics Fluids			1
	1.0	General Comments		1
	1.1	Parahydrogen		1
		1.1.1	Dielectric Constant of Solid Parahydrogen	1
		1.1.2	Refractive Index of Hydrogen	1
		1.1.3	Thermal Conductivity.	1
		1.1.4	TAB Code	2
	1.2	Oxygen		13
		1.2.1	P-V-T Relationship of Oxygen	13
2.	Cryogenic Metrology (Instrumentation).			14
	2.0	General Comments		14
	2.1	Temperature		14
		2.1.1	Sample Holder Modification	14
		2.1.2	Pyroelectric Thermometry Studies	14
			Table I Change in pyroelectric coefficient due to a depolarizing field (300°K)	15
		2.1.3	Pyroelectric Effect in Single Crystals	15
	2.2	Pressure		16
		2.2.1	Piezoresistance Effect in Materials	16
			Table II Resistivity of ytterbium wire	16
			Fig. 1 Resistance Change vs. Pressure at Constant Temperature	17
3.	Consultation and Advisory Services			19
	3.0	General Comments		19
	3.1	Centaur Program		19
		3.1.1	Stratification and Pressurization	19
		3.1.2	Flight Data Analysis	19
	3.2	Rover Program		19
	3.3	NERVA Program		19
4.	Cryogenic Flow Processes			21
	4.0	General Comments		21
	4.1	Analytical		21
	4.2	Experimental		22
5.	Liquid-Solid Hydrogen Studies			23
	5.0	General Comments		23
	5.1	Project Objectives-Task 3		23
	5.2	Project Status		23
	5.3	Future Plans		24
6.	Thermal Conductivity of Solids			25
	6.0	General Comments		25
	6.1	Program Status		25

PHASE OF TASK ↑ / TASK ↓ 3150440	Fluid Properties	Thermofunctions, p-H_2	Equation of state, p-H_2	Dielectric Constant, solid p-H_2	Index of Refraction, p-H_2	Thermal conductivity, p-H_2	TAB Code, p-H_2	P-V-T, Oxygen
Task Completed		X						
For Latest Report or Publication on This Task See: Provisional (P) or Final (F)		F	P				P	P
For Latest Report or Publication on This Task See: item #		a	a	This report	This report	This report		5
For Latest Report or Publication on This Task See: page		19	17					11
For Latest Report or Publication on This Task See: Quart. Report #		19	20				18-23	18
Est. Completion Date				6/67	4/67	-	10/66	10/66
Report in Press								
Report Composition			X					
Data Analysis							100	5
Data Taking					10			100
Apparatus Construction				100	100	100		100
Apparatus Designing								
Preliminary Planning								
Not Started								
Active Coord. with Lewis, MSFC, LASL								
Item Number		1.	2.	3.	4.	5.	6.	7.

PHASE OF TASK ↑ / TASK → 3150460	Temperature	Pressure
Task Completed		
For Latest Report or Publication on This Task See: Provisional (P) or Final (F)		
For Latest Report or Publication on This Task See: item #		
For Latest Report or Publication on This Task See: page		
For Latest Report or Publication on This Task See: Quart. Report #		
Est. Completion Date		
Report in Press		
Report Composition		X
Data Analysis	X	X
Data Taking	X	X
Apparatus Construction		
Apparatus Designing		
Preliminary Planning		
Not Started		
Active Coord. with Lewis, MSFC, LASL		
Item Number	2.1	2.2

PHASE OF TASK ↑ / TASK → 3150451	Centaur Program, General Consultation	1 Stratification & Pressurization	2 Flight Data Analysis
Task Completed			
For Latest Report or Publication on This Task See: Provisional (P) or Final (F)			
For Latest Report or Publication on This Task See: item #			
For Latest Report or Publication on This Task See: page			
For Latest Report or Publication on This Task See: Quart. Report #			
Est. Completion Date	*	*	*
Report in Press			
Report Composition			
Data Analysis		X	X
Data Taking			
Apparatus Construction			
Apparatus Designing			
Preliminary Planning			
Not Started			
Active Coord. with Lewis, MSFC, LASL	X	X	X
Item Number	3.1	3.1	3.1

* Continuing effort

PHASE OF TASK ↑ / TASK ↓		3150400 Rover Program	NERVA Program
Task Completed			
For Latest Report or Publication on This Task See	Provisional (P) or Final (F)		
	item #		
	page		
	Quart. Report #		
Est. Completion Date		*	*
Report in Press			
Report Composition			
Data Analysis			
Data Taking			
Apparatus Construction			
Apparatus Designing			
Preliminary Planning			
Not Started			
Active Coord. with Lewis, MSFC, LASL		X	X
Item Number		3.2	3.3

* Continuing effort

Item Number	4.
PHASE OF TASK → / TASK ↓	3150470 Cryogenic Flow Processes; *Continuing effort
Active Coord. with Lewis, MSFC, LASL	
Not Started	
Preliminary Planning	
Apparatus Designing	
Apparatus Construction	
Data Taking	X
Data Analysis	X
Report Composition	X
Report in Press	
Est. Completion Date	*
For Latest Report or Publication on This Task See: Quart. Report #	This report
For Latest Report or Publication on This Task See: page	
For Latest Report or Publication on This Task See: item #	
For Latest Report or Publication on This Task See: Provisional (P) or Final (F)	
Task Completed	

PHASE OF TASK ↑ / TASK →	3150450 Solid-Liquid Hydrogen Studies	Mass-Energy Balance Experiment	Solid Particle Studies	Heat Transfer Studies
Task Completed				
For Latest Report or Publication on This Task See: Provisional (P) or Final (F)				
For Latest Report or Publication on This Task See: item #				
For Latest Report or Publication on This Task See: page				
For Latest Report or Publication on This Task See: Quart. Report #				
Est. Completion Date		5/15/66		
Report in Press		X		
Report Composition				
Data Analysis				
Data Taking				
Apparatus Construction			X	
Apparatus Designing			X	
Preliminary Planning			X	
Not Started				X
Active Coord. with Lewis, MSFC, LASL		X	X	X
Item Number				

Task Completed		
For Latest Report or Publication on This Task See	Provisional (P) or Final (F)	
	item #	
	page	
	Quart. Report #	
Est. Completion Date		*
Report in Press		
Report Composition		
Data Analysis		
Data Taking		
Apparatus Construction		X
Apparatus Designing		
Preliminary Planning		
Not Started		
Active Coord. with Lewis, MSFC, LASL		X
PHASE OF TASK ↑ / TASK →		3150430 Thermal Conductivity of Metals * Continuing effort
Item Number		6.

1. Physical Properties of Cryogenic Fluids

1.0 General Comments

Personnel contributing during this period were D. E. Diller, W. J. Hall, H. M. Roder, L. A. Weber, and B. A. Younglove.

1.1 Parahydrogen

1.1.1 Dielectric Constant of Solid Parahydrogen

The new capacitor cell, bomb, and electrical circuitry have been installed in the cryostat. Checks for electrical continuity, gas leaks, thermometry, and behavior of the capacitor cell at room temperature have been completed. The system is ready for performance testing with solid hydrogen.

1.1.2 Refractive Index of Hydrogen

Test measurements on normal hydrogen have been resumed at 298.15°K and pressures to 100 atm. Sample purification and precision temperature control are now in use. The hoped-for precision in the Lorentz-Lorenz function has been achieved for these conditions with the result

$$L - L \equiv \frac{n^2 - 1}{n^2 + 2} \cdot \frac{1}{\rho} = 1.0340 \pm 0.0002 \frac{cm^3}{g} \text{ at } \lambda = 5462 \text{ Å}$$

independent of pressure from 25 to 100 atm. Comparative measurements on normal and parahydrogen at 100°K are planned next.

1.1.3 Thermal Conductivity

The test experiments with helium gas mentioned in the two preceding reports have been completed. Isotherms were determined at 282, 260, 240, 220, 200, 180, 160, 140, 120, 100, 87, 70, 50, 30, and 20°K. Maximum pressure was 30 atm on most isotherms but extended to as high as 50 atm.

Conductivity values for low pressure air from 40 to 110°K in steps of 5°K as well as 14 points along the 100°K isotherm at pressures up to 5 atm have also been measured in the system. The lowest experimental pressure encountered was 15 μ Hg. The lowest pressure at which conductivity values could be measured without appreciable error was 340 μ.

Calculations are in progress to compare the low pressure limiting conductivities of helium with kinetic theory and to compare the conductivity second virial coefficients with Enskog theory.

These test experiments have proved to be illuminating since the results have displayed certain inconsistencies which can be considerably reduced by applying corrections or operating procedures based on reasonable assumptions about heat flows and temperature gradients in the heavy-walled sample container. Some of the test runs were conducted with appreciable amounts of convection in the total heat flow. We now have enough knowledge to precompute those values of temperature gradient and plate spacing which will limit the contribution of convection to 1% or less. This insight into the behavior of the apparatus will be useful in carrying out the measurements on hydrogen.

The above tests with helium and air were carried out with NBS funds. This experiment now becomes temporarily inactive due to assignment of Hans M. Roder to direction of the Compilation Unit of the Cryogenic Data Center.

1.1.4 TAB Code

The final codes for hydrogen properties, which are listed here, are specific heat and sound velocity furnished as functions of pressure and enthalpy. When the pressure, P, is entered in psia, and the enthalpy, H, in BTU/lb., sound velocity is returned from the codes in ft./sec., and specific heats in BTU/lb.-°R.

The values of specific heat and sound velocity were recalculated as described in Progress Report #22, June 30, 1966. From the triple point to 400 BTU/lb., the values given for specific heat and sound velocity are taken from NBS Monograph 94. Requests for values below the solid line return the value at the solid line. Requests inside the liquid-vapor dome return (1) a fictitious sound velocity consisting of an average of the liquid and vapor boundary values weighted according to the proportions of the two phases present, (2) a similarly fictitious specific heat at constant volume, C_v, (3) a specific heat at constant pressure, C_p, or specific heat ratio which is the largest number available in the computer ($\sim 1. \times 10^{307}$).

From 400 to 2,000 BTU/lb., the values were calculated using the modified Benedict-Webb-Rubin equation from NBS Technical Note 130. From 2,000 to 20,000 BTU/lb., the equation of state of Woolley, Scott, and Brickwedde* was used. Requests above 20,000 return the value at 20,000 BTU/lb. Pressures outside the range of the code (1 to 5,000 psia) return values which have been extrapolated from the last available values inside the range.

The error in sound velocity is less than 1% from the values given by the references, but the references may be in error by 1% to 2% in some ranges. The error in C_p, C_v, and their ratio is 1% except for two regions: In the region of dissociation (from 9,200 to 20,000 BTU/lb.) the error may be as high as 5%. In the region near critical, -45 to 75 BTU/lb., 150 to 300 psia, the error is about 5%, and very near critical may be much larger than that because of uncertainty in the reference data. (See discussion of errors in Monograph 94.)

The programs PHCP, PHCV, and PHGAMM are in one Fortran function with three entry points. The Fortran statement:

CP = PHCP(P,H)

where P is pressure in psia and H is enthalpy in BTU/lb., will cause the specific heat at constant pressure corresponding to P and H, to be

---

*H. W. Woolley, R. B. Scott, and F. G. Brickwedde, J. Research NBS 41, 397 (1948); RP 1932.

stored in location CP. Similarly;

CV = PHCV(P, H)

returns the specific heat at constant volume to location CV;

RATIO = PHGAMM(P, H)

returns the specific heat ratio to computer location RATIO; and

SOUND = PHSOUN(P, H)

returns the velocity of sound to location SOUND.

The program listings are as follows:

```
      FUNCTION PHSOUN (PRES,ENTH)
      DIMENSION LOC(14),JP(14),MX(14),BP(14),DP(14),BH(14),DH(14),V(307)
     1R(19),HL(19),HV(19),VL(19),VG(19),HS(10)
      DATA(LOC=1,2,3,4,31,67,97,121,124,227,170,202,227,263)
      DATA(JP=5,5,5,5,3,6,4,7,7,9,4,5,9,9)
      DATA(MX=0,0,0,0,1,4,2,2,2,1,2,3,7,7)
      DATA(BP=1.,10.,100.,1000.,-3000.,0,2000.,-40.,500.,1000.,400.,80.,
     10,0)
      DATA(DP=9.,90.,900.,4000.,4000.,1000.,1000.,180.,500.,500.,200.,80
     1.,50.,50.)
      DATA(BH=5000.,5000.,5000.,5000.,600.,400.,-50.,100.,100.,-100.,
     1-110.,-140.,0,20.)
      DATA(DH=3000.,3000.,3000.,3000.,400.,50.,90.,50.,50.,50.,30.,35.,
     15.,20.)
      DATA(R=1.022,2.,4.,8.,14.,25.,43.,69.,99.,128.,151.,165.,176.,182.
     1,185.,186.5,187.25,187.46875,187.506)
      DATA(HL=-132.8,-129.13,-124.25,-117.79,-110.86,-101.3,-89.04,-74.2
     12,-58.58,-43.43,-30.07,-20.56,-11.13,-4.27,1.17,5.54,10.83,14.29,
     216.36)
      DATA(HV=60.31,65.11,70.59,76.35,80.98,85.11,87.4,86.54,81.94,74.15
     1,64.83,56.86,47.34,39.56,33.46,28.34,22.31,18.66,16.55)
      DATA(VL=4177.,4049.,3903.,3743.,3604.,3406.,3158.,2826.,2498.,2140
     1.,1913.,1733.,1556.,1343.,1236.,1183.,1167.,1153.,1150.)
      DATA(VG=1001.,1040.,1083.,1129.,1161.,1195.,1220.,1237.,1242.,1236
     1.,1221.,1215.,1198.,1174.,1162.,1157.,1154.,1151.,1150.)
      DATA(HS=-132.8,-109.96,-87.59,-65.71,-44.27,-23.18,-2.45,18.06,
     138.32,58.50)
      DATA((V(I),I=1,169)=7062.,7063.,7073.,7165.,7565.,8766.,8767.,8774
     1.,8844.,9147.,9929.,10016.,10051.,10107.,10364.,10296.,10689.,1096
     20.,11117.,11375.,10460.,10921.,11403.,11799.,12169.,10653.,11137.,
     311669.,12241.,12751.,1911.,2981.,4403.,2594.,3487.,4561.,3187.,399
     46.,4898.,3739.,4471.,5264.,4235.,4906.,5597.,4693.,5292.,5889.,
     55097.,5653.,6202.,5471.,5991.,6500.,5821.,6309.,6784.,6151.,6610.,
     67056.,6464.,6896.,7317.,6755.,7165.,7565.,2413.,2746.,3212.,3717.,
     74209.,4682.,2496.,2804.,3224.,3662.,4074.,4453.,2569.,2861.,3249.,
     83661.,4056.,4426.,2641.,2920.,3283.,3671.,4051.,4409.,2714.,2981.,
     93323.,3691.,4055.,4403.,5092.,5830.,6407.,6486.,4225.,5062.,5722.,
     A6224.,3638.,4472.,5151.,5722.,3356.,4078.,4721.,5279.,3238.,3842.,
     B4409.,4931.,3212.,3717.,4209.,4682.,1266.,1383.,1652.,1934.,2673.,
     C3284.,3799.,1561.,1655.,1819.,2002.,2562.,3087.,3556.,1808.,1885.,
     D1997.,2126.,2551.,2986.,3402.,2014.,2076.,2159.,2257.,2585.,2943.,
     E3301.,2176.,2229.,2294.,2372.,2635.,2933.,3245.,2307.,2349.,2404.,
     F2469.,2690.,2943.,3219.,2406.,2446.,2496.,2554.,2746.,2966.,3212.)
      DATA((V(I),I=170,307)=  4240.,4515.,4739.,4937.,3678.,3988.,4255.,
     14494.,3116.,3496.,3808.,4078.,2564.,3019.,3378.,3680.,2112.,2611.,
     23000.,3324.,1831.,2321.,2707.,3034.,1760.,2157.,2508.,2817.,1776.,
     32092.,2394.,2673.,4450.,4572.,4678.,4778.,4876.,3599.,3746.,3880.,
     44011.,4136.,2752.,2980.,3172.,3340.,3493.,1784.,2084.,2386.,2628.,
     52833., 750.,1120.,1670.,1995.,2246.,4786.,5200.,5600., 960.,1407.,
     61714.,1925.,2094.,2246.,4078.,4636.,5092., 900.,1314.,1633.,1853.,
     72024.,2176.,3436.,4078.,4583., 893.,1246.,1567.,1788.,1959.,2112.,
     82954.,3615.,4150., 915.,1212.,1516.,1730.,1904.,2053.,2673.,3284.,
     93799., 998.,1202.,1480.,1683.,1855.,2000.,    0.,    0.,    0.,1114.,
     A1237.,1400.,1575.,1709.,1845.,1004., 900.,1148.,1190.,1299.,1421.,
```

```
B1543.,1658.,1773.,1155.,1166.,1232.,1293.,1384.,1477.,1570.,1663.,
C1757.,1292.,1311.,1350.,1399.,1468.,1549.,1622.,1698.,1776.)
  P=PRES
  H=ENTH
  IF(H.LT.400.) GO TO 6
  IF(H.LT.5000.)GO TO 4
  IF(H.GE.20000.) H=19999.99999
  IF(P.GE.100.) GO TO 2
  IF(P.GE.10.)  GO TO 1
  N=1
  GO TO 33
1 N=2
  GO TO 33
2 IF(P.GE.1000.) GO TO 3
  N=3
  GO TO 33
3 N=4
  GO TO 33
4 IF(H.LT.600.) GO TO 5
  N=5
  GO TO 33
5 N=6
  GO TO 33
6 IF(P.LT.2000.) GO TO 7
  N=7
  GO TO 30
7 IF(H.LT.100.) GO TO 9
  IF(P.GE.500.) GO TO 8
  N=8
  GO TO 33
8 N=9
  GO TO 33
9 IF(P.LT.400.) GO TO 11
  IF(P.LT.1000.) GO TO 10
  N=10
  GO TO 30
10 N=11
  GO TO 30
11 IF(H.GE.0.) GO TO 12
  N=12
  IF(H.LT.-132.7285+P*0.08224) GO TO 30
  GO TO 20
12 IF(H.GE.20.) GO TO 13
  N=13
  GO TO 20
13 N=14
20 IF(P.GT.187.506) GO TO 33
  DO 21 I=2,19
  IF(P-R(I))22,22,21
21 CONTINUE
22 F=(P-R(I-1))/(R(I)-R(I-1))
  CHL=HL(I-1)+(HL(I)-HL(I-1))*F
  CHV=HV(I-1)+(HV(I)-HV(I-1))*F
  IF(H.LT.CHL.OR.H.GT.CHV) GO TO 33
```

```
      SVL=VL(I-1)+(VL(I)-VL(I-1))*F
      SVG=VG(I-1)+(VG(I)-VG(I-1))*F
      F=(H-CHL)/(CHV-CHL)
      PHSOUN=SVL+(SVG-SVL)*F
      RETURN
   30 PR=P/587.84
      I=PR
      IF(I.GT.8) I=8
      F=PR-I
      FP=1.-F
      G=FP*HS(I+1)+F*HS(I+2)
      IF(H.LT.G)H=G
   33 FP=(P-BP(N))/DP(N)
      IP=FP
      IF(IP.GT.MX(N)) IP=MX(N)
      F=FP-IP
      FP=1.-F
      FH=(H-BH(N))/DH(N)
      IH=FH
      FF=FH-IH
      FH=1.-FF
      I=IH*JP(N)+IP+LOC(N)
      J=I+JP(N)
      PHSOUN=FP*FH*V(I)+F*FH*V(I+1)+FP*FF*V(J)+F*FF*V(J+1)
      RETURN
      END
```

```
 FUNCTION PHCP(PRES,ENTH)
 COMMON/HPHEAT/ CP(665),CV(665)
 DIMENSION LOC(17),JP(17),MX(17),BP(17),DP(17),BH(17),DH(17),R(19),
1HL(19),HV(19),HS(10),CVL(19),CVV(19)
 DATA(CVV=1.483,1.488,1.504,1.525,1.551,1.583,1.619,1.666,1.733,
11.822,1.915,2.013,2.137,2.204,2.275,2.315,2.336,2.342,2.343)
 DATA(CVL=1.126,1.152,1.234,1.305,1.365,1.419,1.459,1.491,1.525,
11.560,1.603,1.644,1.756,1.883,2.091,2.241,2.317,2.339,2.343)
 DATA(R=1.022,2.,4.,8.,14.,25.,43.,69.,99.,128.,151.,165.,176.,182.
1,185.,186.5,187.25,187.46875,187.506)
 DATA(HL=-132.8,-129.13,-124.25,-117.79,-110.86,-101.3,-89.04,-74.2
12,-58.58,-43.43,-30.07,-20.56,-11.13,-4.27,1.17,5.54,10.83,14.29,
216.36)
 DATA(HV=60.31,65.11,70.59,76.35,80.98,85.11,87.4,86.54,81.94,74.15
1,64.83,56.86,47.34,39.56,33.46,28.34,22.31,18.66,16.55)
 DATA(HS=-132.8,-109.96,-87.59,-65.71,-44.27,-23.18,-2.45,18.06,
138.32,58.50)
 DATA(LOC=1,21,63,84,133,141,156,160,256,237,273,313,355,404,439,
1523,558)
 DATA(JP=5,6,3,7,2,3,9,9,4,4,5,3,7,7,7,7,9)
 DATA(MX=3,4,1,5,0,1,3,3,2,2,3,1,5,5,5,5,7)
 DATA(BP=1000.,0,20.,0,15.,0,0,1000.,2000.,2000.,1000.,600.,0,0,300
1.,0,140.)
 DATA(DP=1000.,200.,40.,5.,4985.,2500.,250.,1000.,1000.,1000.,250.,
1200.,100.,100.,50.,50.,20.)
 DATA(BH=9200.,9200.,9200.,9200.,2600.,1000.,200.,200.,80.,-45.,-80
1.,-125.,-135.,120.,-45.,60.,-50.)
 DATA(DH=3600.,1800.,1800.,1800.,2200.,400.,100.,100.,40.,25.,40.,
125.,15.,20.,15.,15.,10.)
 DATA((CP(I),I=439,557)= .9260,.8653,.8181,.7799,.7479,.7207,.6971,
1.8979,.8104,.7490,.7029,.6664,.6360,.6110,.9189,.7855,.7012,.6424,
2.5987,.5648,.5373,.9962,.7935,.6801,.6072,.5558,.5173,.4874,1.125,
3.8437,.6943,.6057,.5456,.5019,.4687,1.227,.9052,.7409,.6406,.5728,
4.5236,.4864,1.226,.9639,.8085,.7069,.6351,.5821,.5410,1.163,.9961,
5.8757,.7871,.7199,.6668,.6242,1.086,1.004,.9285,.8642,.8097,.7630,
6.7233,1.030,1.004,.9683,.9306,.8931,.8576,.8249,.9984,1.005,.9986,
7.9835,.9638,.9414,.9183,.9872,1.012,1.024,1.026,1.021,1.011,.9977,
8.2622,.5,2.,1.988,1.741,1.395,1.163,.3095,.53,.85,1.171,1.224,1.16
93,1.086,.3654,.5427,.7354,.8998,1.004,1.034,1.03,.4282,.5587,.6976
A,.8174,.9077,.9699,.9984,.4942,.5992,.7064,.802,.8823,.9449,.9872)
 DATA((CP(I),I=558,665)= 1.255,1.199,1.147,1.099,1.060,1.024,.9928,
1.9640,.9385,1.529,1.366,1.249,1.161,1.091,1.034,.9871,.9476,.9134,
21.811,1.718,1.456,1.284,1.162,1.072,1.001,.9445,.8979,2.837,2.744,
32.017,1.583,1.333,1.170,1.056,.9715,.9054,0.000,4.578,3.851,2.072,
41.688,1.362,1.164,1.033,.9377,0.000,10.51,9.787,3.748,2.244,1.633,
51.333,1.132,.9962,0,0,37.29,7.516,3.177,2.040,1.541,1.259,1.079,0,
60.000,40.00,9.880,3.905,2.373,1.737,1.387,1.169,0.000,0.000,25.93,
77.327,3.608,2.390,1.792,1.453,1.227,0.000,6.570,7.716,4.255,2.784,
82.100,1.692,1.426,1.238,3.000,3.305,3.395,2.566,2.066,1.744,1.515,
91.342,1.210,1.922,1.940,1.922,1.748,1.588,1.454,1.341,1.247,1.163)
 DATA((CV(I),I=558,665)= 1.353,1.531,1.529,1.527,1.525,1.523,1.522,
11.521,1.520,1.567,1.560,1.554,1.549,1.545,1.542,1.539,1.537,1.535,
21.603,1.596,1.585,1.576,1.569,1.563,1.559,1.555,1.552,1.666,1.649,
31.631,1.614,1.601,1.591,1.583,1.576,1.571,0.000,1.795,1.730,1.667,
```

```
 41.645,1.628,1.615,1.604,1.595,0.000,2.172,2.024,1.876,1.768,1.701,
 51.655,1.638,1.625,0,0,2.336,2.120,1.942,1.817,1.732,1.692,1.666,0,
 60.000,2.442,2.244,2.065,1.898,1.791,1.745,1.709,0.000,0.000,2.356,
 72.234,2.093,1.943,1.830,1.773,1.732,0.000,2.506,2.227,2.144,2.043,
 81.927,1.856,1.793,1.743,2.150,2.372,2.093,2.037,1.959,1.887,1.828,
 91.773,1.757,1.855,1.977,2.006,1.937,1.871,1.833,1.792,1.764,1.743)
  DATA(VERYBIG=37777777777777777B)
  KTR=1
  GO TO 1
  ENTRY PHCV
  KTR=2
  GO TO 1
  ENTRY PHGAMM
  KTR=3
1 P=PRES
  H=ENTH
  IF(H.LT.200.) GO TO 9
  IF(H.LT.9200.) GO TO 5
  IF(H.GE.20000.) H=19999.99999
  IF(P.LT.100.) GO TO 3
  IF(P.LT.1000.) GO TO 2
  N=1
  GO TO 33
2 N=2
  GO TO 33
3 IF(P.LT.30.) GO TO 4
  N=3
  GO TO 33
4 N=4
  GO TO 33
5 IF(H.LT.1000.) GO TO 7
  IF(H.LT.2600.) GO TO 6
  N=5
  GO TO 33
6 N=6
  GO TO 33
7 IF(P.GE.1000.) GO TO 8
  N=7
  GO TO 33
8 N=8
  GO TO 33
9 IF(P.LT.600.) GO TO 13
  IF(P.LT.2000.) GO TO 11
  IF(H.LT.80.) GO TO 10
  N=9
  GO TO 33
10 N=10
  GO TO 30
11 IF(P.LT.1000.) GO TO 12
  N=11
  GO TO 30
12 N=12
  GO TO 30
13 IF(H.GE.-45.) GO TO 14
```

```
      N=13
      IF(H.LT.-132.7285+P*0.08224) GO TO 30
      GO TO 20
   14 IF(H.LT.120.) GO TO 15
      N=14
      GO TO 33
   15 IF(P.LT.300.) GO TO 16
      N=15
      GO TO 33
   16 IF(H.LT.60.) GO TO 17
      N=16
      GO TO 20
   17 N=17
   20 IF(P.GT.187.506) GO TO 33
      DO 21 I=2,19
      IF(P-R(I))22,22,21
   21 CONTINUE
   22 F=(P-R(I-1))/(R(I)-R(I-1))
      CHL=HL(I-1)+(HL(I)-HL(I-1))*F
      CHV=HV(I-1)+(HV(I)-HV(I-1))*F
      IF(H.LT.CHL.OR.H.GT.CHV) GO TO 33
      IF(KTR.EQ.2) GO TO 23
      PHCP=VERYBIG
      RETURN
   23 CL=CVL(I-1)+(CVL(I)-CVL(I-1))*F
      CG=CVV(I-1)+(CVV(I)-CVV(I-1))*F
      PHCP=CL+(CG-CL)*(H-CHL)/(CHV-CHL)
      RETURN
   30 F=P/587.84
      I=F
      IF(I.GT.8) I=8
      F=F-I
      V=(1.0-F)*HS(I+1)+F*HS(I+2)
      IF(H.LT.V) H=V
   33 FP=(P-BP(N))/DP(N)
      IP=FP
      IF(IP.GT.MX(N)) IP=MX(N)
      F=FP-IP
      FP=1.-F
      FH=(H-BH(N))/DH(N)
      IH=FH
      FF=FH-IH
      FH=1.-FF
      I=IH*JP(N)+IP+LOC(N)
      J=I+JP(N)
      IF(KTR.EQ.2) GO TO 35
      HCP=FP*FH*CP(I)+F*FH*CP(I+1)+FP*FF*CP(J)+F*FF*CP(J+1)
      IF(N.LT.13) GO TO 34
      R=H+500.
      HCP=HCP/(18240.46942/R-425696635.2/R/R/R-65.21553314+.07110647112*
     1R-2.644991367E-8*R*R*R)
   34 IF(KTR.GE.2) GO TO 35
      PHCP=HCP
      RETURN
```

```
35 PHCP=FP*FH*CV(I)+F*FH*CV(I+1)+FP*FF*CV(J)+F*FF*CV(J+1)
   IF(KTR.LT.3) RETURN
   PHCP=HCP/PHCP
   RETURN
   END
   SUBROUTINE H C SUB P
   COMMON/HPHEAT/CP(665),CV(665)
   DATA((CP(I),I=1,132)=3.792,3.790,3.788,3.786,3.785,4.076,4.059,
  14.050,4.044,4.040,4.707,4.563,4.494,4.454,4.426,6.364,5.841,5.588,
  25.442,5.345,3.796,3.794,3.793,3.793,3.792,3.792,3.958,3.941,3.931,
  33.928,3.927,3.925,4.250,4.150,4.107,4.092,4.083,4.076,4.900,4.561,
  44.435,4.377,4.342,4.318,6.143,5.342,4.990,4.848,4.764,4.707,8.032,
  56.592,5.918,5.629,5.460,5.347,10.41,8.284,7.400,6.875,6.568,6.364,
  63.797,3.796,3.795,3.979,3.958,3.949,4.360,4.247,4.200,5.246,4.883,
  74.730,6.854,6.076,5.742,9.123,7.861,7.312,11.81,10.10,9.348,3.819,
  83.803,3.800,3.799,3.798,3.797,3.797,4.238,4.049,4.012,3.996,3.985,
  93.978,3.973,5.650,4.733,4.544,4.454,4.398,4.360,4.332,8.761,6.366,
  A5.826,5.556,5.371,5.246,5.155,13.27,9.110,8.091,7.553,7.139,6.861,
  B6.660,18.46,12.62,11.16,10.34,9.623,9.148,8.808,23.90,16.56,14.73,
  C13.60,12.56,11.87,11.39)
   DATA((CP(I),I=133,236)= 3.472,3.540,3.503,3.514,3.629,3.624,3.799,
  13.785,3.898,4.125,4.196,3.699,3.839,3.913,3.548,3.639,3.696,3.489,
  23.546,3.585,3.472,3.513,3.540,2.471,3.189,3.655,3.860,3.904,3.633,
  33.326,3.076,2.866,2.605,2.949,3.228,3.437,3.576,3.698,3.577,3.411,
  43.236,2.939,3.151,3.331,3.477,3.591,3.819,3.800,3.704,3.584,3.281,
  53.434,3.570,3.685,3.771,3.975,4.043,4.059,4.057,3.573,3.676,3.769,
  63.850,3.914,4.081,4.152,4.175,4.176,3.774,3.845,3.909,3.965,4.013,
  74.146,4.211,4.237,4.241,3.873,3.926,3.974,4.017,4.055,4.164,4.223,
  84.250,4.258,3.908,3.949,3.987,4.021,4.052,4.144,4.198,4.228,4.240,
  93.898,3.931,3.962,3.990,4.016,4.096,4.148,4.179,4.196)
   DATA((CP(I),I=237,354)= 1.859,1.088,0.462,0,2.281,1.638,1.079,0,
  12.610,2.070,1.516,0.840,2.870,2.380,1.916,1.350,3.080,2.613,2.223,
  21.787,3.259,2.790,2.455,2.106,3.467,3.026,2.716,2.448,3.578,3.196,
  32.921,2.683,3.633,3.326,3.076,2.866,1.934,1.697,1.470,1.280,1.076,
  42.750,2.511,2.308,2.127,1.954,3.453,3.126,2.892,2.709,2.551,4.033,
  53.612,3.331,3.123,2.958,4.361,3.937,3.646,3.429,3.259,4.363,4.055,
  63.814,3.623,3.467,4.152,3.997,3.843,3.704,3.578,3.905,3.868,3.798,
  73.716,3.633,1.089,0.891,0.700,1.836,1.611,1.417,2.471,2.244,2.048,
  83.094,2.789,2.562,3.787,3.320,3.021,4.562,3.854,3.453,5.298,4.344,
  93.838,5.762,4.710,4.144,5.757,4.872,4.338,5.381,4.819,4.399,4.871,
  A4.614,4.344,4.402,4.351,4.214,4.037,4.094,4.056,3.764,3.881,3.905)
   DATA((CP(I),I=355,438)= 1.008,.9365,.8657,.8000,.7400,.0000,.0000,
  11.190,1.101,1.025,.9500,.8864,.8249,.7596,1.296,1.201,1.120,1.050,
  2.9860,.9267,.8677,1.365,1.240,1.142,1.064,1.002,.9471,.8973,1.446,
  31.260,1.125,1.032,.9625,.9064,.8590,1.682,1.345,1.106,.9782,.8947,
  4.8335,.7857,2.164,1.598,1.130,.9260,.8181,.7479,.6971,.4942,.7064,
  5.8830,.9880,1.024,1.021,.9977,.5807,.7459,.8907,.9946,1.052,1.077,
  61.080,.6575,.7922,.9136,1.011,1.073,1.113,1.132,.7164,.8282,.9306,
  71.017,1.079,1.126,1.155,.7496,.8424,.9284,1.004,1.064,1.109,1.142)
   DATA((CV(I),I=355,438)= 1.100,1.057,1.017,.9735,.9310,0.000,0.000,
  11.291,1.252,1.211,1.170,1.131,1.090,1.044,1.406,1.385,1.362,1.335,
  21.305,1.272,1.234,1.460,1.452,1.441,1.428,1.413,1.395,1.373,1.496,
  31.487,1.482,1.476,1.470,1.462,1.452,1.537,1.521,1.510,1.506,1.503,
  41.500,1.496,1.589,1.561,1.538,1.528,1.524,1.523,1.522,1.478,1.580,
```

```
51.598,1.601,1.608,1.610,1.611,1.478,1.542,1.566,1.578,1.594,1.604,
61.611,1.479,1.525,1.552,1.571,1.590,1.604,1.615,1.481,1.519,1.547,
71.570,1.593,1.610,1.621,1.486,1.521,1.550,1.576,1.600,1.618,1.632)
 END
 SUBROUTINE H C SUB V
 COMMON/HPHEAT/CP(665),CV(665)
 DATA((CV(I),I=  1,132)= 2.808,2.808,2.808,2.809,2.809,3.093,3.077,
13.070,3.066,3.063,3.723,3.580,3.514,3.474,3.448,5.380,4.858,4.607,
24.462,4.366,2.811,2.809,2.809,2.809,2.808,2.808,2.973,2.956,2.947,
32.944,2.943,2.942,3.264,3.166,3.123,3.108,3.099,3.093,3.914,3.577,
43.451,3.393,3.358,3.335,5.157,4.357,4.006,3.864,3.780,3.723,7.047,
55.607,4.933,4.645,4.476,4.363,9.426,7.299,6.415,5.890,5.584,5.380,
62.812,2.810,2.810,2.993,2.973,2.964,3.375,3.262,3.215,4.260,3.898,
73.745,5.869,5.090,4.757,8.138,6.876,6.327,10.83,9.112,8.363,2.834,
82.818,2.815,2.813,2.813,2.812,2.812,3.253,3.064,3.027,3.010,3.000,
92.993,2.988,4.665,3.747,3.559,3.469,3.413,3.375,3.347,7.775,5.381,
A4.841,4.571,4.386,4.261,4.170,12.28,8.125,7.106,6.568,6.154,5.876,
B5.674,17.47,11.64,10.18,9.352,8.638,8.163,7.823,22.91,15.57,13.74,
C12.61,11.57,10.89,10.40)
 DATA((CV(I),I=133,236)= 2.487,2.529,2.518,2.533,2.644,2.648,2.813,
12.809,2.912,2.953,2.986,2.714,2.746,2.775,2.563,2.583,2.604,2.503,
22.513,2.523,2.487,2.508,2.529,1.486,1.563,1.617,1.652,1.679,1.751,
31.777,1.784,1.784,1.621,1.702,1.768,1.822,1.866,1.963,1.993,1.991,
41.972,1.954,2.017,2.070,2.112,2.152,2.254,2.279,2.277,2.257,2.296,
52.346,2.393,2.437,2.462,2.546,2.618,2.681,2.736,2.587,2.617,2.646,
62.672,2.689,2.746,2.795,2.837,2.874,2.789,2.804,2.819,2.833,2.843,
72.880,2.912,2.939,2.962,2.888,2.897,2.906,2.914,2.922,2.947,2.969,
82.988,3.004,2.923,2.929,2.934,2.940,2.945,2.964,2.981,2.996,3.009,
92.912,2.917,2.921,2.925,2.929,2.946,2.961,2.974,2.986)
 DATA((CV(I),I=237,354)= 1.367,1.051,0.785,0,1.507,1.290,1.069,0,
11.575,1.485,1.255,0.908,1.606,1.579,1.453,1.202,1.617,1.627,1.572,
21.410,1.635,1.648,1.638,1.557,1.667,1.690,1.689,1.668,1.700,1.728,
31.739,1.732,1.751,1.777,1.784,1.784,1.351,1.271,1.186,1.115,1.020,
41.523,1.510,1.486,1.452,1.404,1.569,1.575,1.576,1.574,1.565,1.579,
51.588,1.597,1.604,1.610,1.600,1.608,1.617,1.627,1.635,1.623,1.635,
61.647,1.659,1.667,1.645,1.662,1.677,1.690,1.700,1.679,1.703,1.723,
71.738,1.751,0.995,0.876,0.797,1.289,1.213,1.155,1.452,1.424,1.387,
81.515,1.510,1.499,1.544,1.546,1.547,1.564,1.564,1.569,1.581,1.572,
91.576,1.598,1.582,1.583,1.608,1.596,1.597,1.612,1.608,1.612,1.610,
A1.617,1.626,1.612,1.627,1.639,1.620,1.638,1.655,1.632,1.657,1.679)
 DATA((CV(I),I=439,557)= 1.528,1.525,1.524,1.523,1.523,1.522,1.522,
11.552,1.546,1.542,1.540,1.539,1.539,1.539,1.582,1.570,1.562,1.557,
21.554,1.553,1.552,1.625,1.601,1.586,1.576,1.570,1.566,1.564,1.690,
31.640,1.614,1.598,1.587,1.579,1.574,1.732,1.675,1.642,1.619,1.603,
41.592,1.584,1.759,1.697,1.662,1.636,1.617,1.604,1.595,1.743,1.700,
51.668,1.644,1.626,1.613,1.604,1.708,1.681,1.658,1.640,1.628,1.617,
61.608,1.668,1.654,1.642,1.632,1.623,1.615,1.611,1.630,1.628,1.624,
71.620,1.617,1.614,1.611,1.601,1.606,1.608,1.610,1.610,1.610,1.611,
81.478,1.700,1.970,2.000,1.937,1.812,1.743,1.478,1.688,1.781,1.837,
91.802,1.748,1.708,1.478,1.616,1.685,1.741,1.709,1.684,1.668,1.478,
A1.559,1.623,1.649,1.641,1.633,1.630,1.478,1.535,1.580,1.595,1.598,
B1.596,1.601)
 END
```

This completes the set of 16 TAB codes as originally outlined in the 16th and 17th Quarterly Reports. A report will be written in which background information and the complete set of program listings will be assembled. Auxiliary codes for saturation properties may also be included.

1.2 Oxygen

1.2.1 P-V-T Relationship of Oxygen

Data taking is completed except for a few supplementary points in the critical region and a few points to determine the nature of the isochore-vapor pressure curve intersection.

Extent of data: 56°K - 300°K in liquid and compressed fluid; pressures to ~330 atm; melting curve determined up to 160 atm; low density gas data from 85°K - 300°K; total data points = 1480.

The task of smoothing and interpolating the data is next.

2. Cryogenic Metrology (Instrumentation)

2.0 General Comments

Personnel contributing to the activities during this period were: S. B. Lang, J. W. Dean, T. M. Flynn, R. J. Richards, L. Rice, and W. McCracken.

2.1 Temperature

2.1.1 Sample Holder Modification

The sample holder described in the 22nd Progress Report was tested extensively during the last three-month period. It was found that poor thermal contact between the thermometer and the pyroelectric sample was causing a considerable error in the measured pyroelectric coefficient. Subsequently, a modification was made in which the filament-wound platinum resistance thermometer was replaced with a very small, thin platinum-film thermometer. This thermometer was cemented to the surface of the ground electrode of the sample holder and was then covered with a conducting silver paint. Thus the thermometer became an integral part of the electrode and was also brought into direct physical contact with the sample. This modification has increased the accuracy of the data considerably.

2.1.2 Pyroelectric Thermometry Studies

Tests were made to determine the effect of large electric fields on the pyroelectric coefficients of the ceramic materials. Because the ceramics are multi-domain polarized materials, it might be expected that an intense electric field could alter the state of polarization. Table I gives the relative changes in value of the pyroelectric coefficients after subjection to the field. The fields used in measuring the following data would have tended to depolarize the sample.

Table I

Change in pyroelectric coefficient due to a depolarizing field (300°K)

Material	Field	Effect on Pyroelectric Coefficient
Clevite Ceramic B	9400 v/cm for 15 minutes	Reduced by 400%
Clevite Ceramic B	9400 v/cm for 24 hours	Reversed in sign
Clevite PZT-4	9400 v/cm for 15 minutes	No effect
Clevite PZT-5A	9400 v/cm for 15 minutes	No effect

No effect was observed on the PZT-4 and PZT-5A because of their very high Curie points. However, the Ceramic B, with its Curie point of 115°C, was strongly affected. In contrast, fields in a direction to polarize the samples improved the reproducibility of the pyroelectric data on all three materials. Thus, it appears that it may be necessary to polarize a pyroelectric thermometer just before use to improve its stability.

2.1.3 Pyroelectric Effect in Single Crystals

A number of pyroelectric single crystals, including both ferroelectric and non-ferroelectric materials, were obtained from various purveyors. It was necessary either to verify or to find the direction of the polar axis in each sample and to determine if each sample contained only a single domain. The following materials were oriented by means of back-reflection Laue X-ray diffraction patterns: tourmaline, silicon carbide, and cadmium selenide. The following crystals were oriented optically with a polarizing microscope using the techniques of locating extinctions and observing interference figures: barium titanate, triglycine sulfate(TGS), potassium tartrate, guanidinium aluminum sulfate hexahydrate(GASH), cadmium sulfide, zinc sulfide, lithium sulfate.

Pyroelectric data has now been obtained between 77 and 300°K on cadmium sulfide, zinc sulfide, lithium sulfate, tourmaline, and GASH.

2.2 Pressure

2.2.1 Piezoresistance Effect in Materials

Several tests have been made on the new sample of ytterbium. The original sample was 0.050 inches in diameter by 1 foot long with a resistance of 0.0816 ohms. This sample was swaged down to 0.027 inches diameter and 34 inches long giving a resistance of 0.830 ohms. Further swaging caused breaking due to work hardening of the sample. A new copper sample holder was made for the 34-inch wire and installed in the probe. Results obtained on the two samples for resistivity as a function of temperature are given in table II.

Table II

Resistivity of Ytterbium Wire

0.050" Diameter		0.027" Diameter	
Temp. °K	ρ ohm in.	Temp °K	ρ ohm in.
300	1.336×10^{-5}	300	1.3616×10^{-5}
76	0.815×10^{-5}	76	0.7889×10^{-5}
20	0.485×10^{-5}	20	0.4805×10^{-5}

The remaining tests were made on the 0.027-in. diameter sample. The pressure coefficient as a function of temperature, $\frac{1}{R}\frac{\Delta R}{\Delta P} = f(T)$, was determined to be:

$$300°K \quad -0.46 \times 10^{-5} \ 1/psi$$

$$76°K \quad -0.9 \times 10^{-5} \ 1/psi$$

$$20°K \quad -1.2 \times 10^{-5} \ 1/psi$$

The graph of figure 1 shows a comparison of the resistance change as a function of pressure for the ytterbium sample and a 1000-ohm 1/4-watt carbon composition resistor.

The repeatability of the resistance of the wire to nine temperature cycles from room temperature to liquid hydrogen temperature was determined. The total change in resistance at the liquid hydrogen

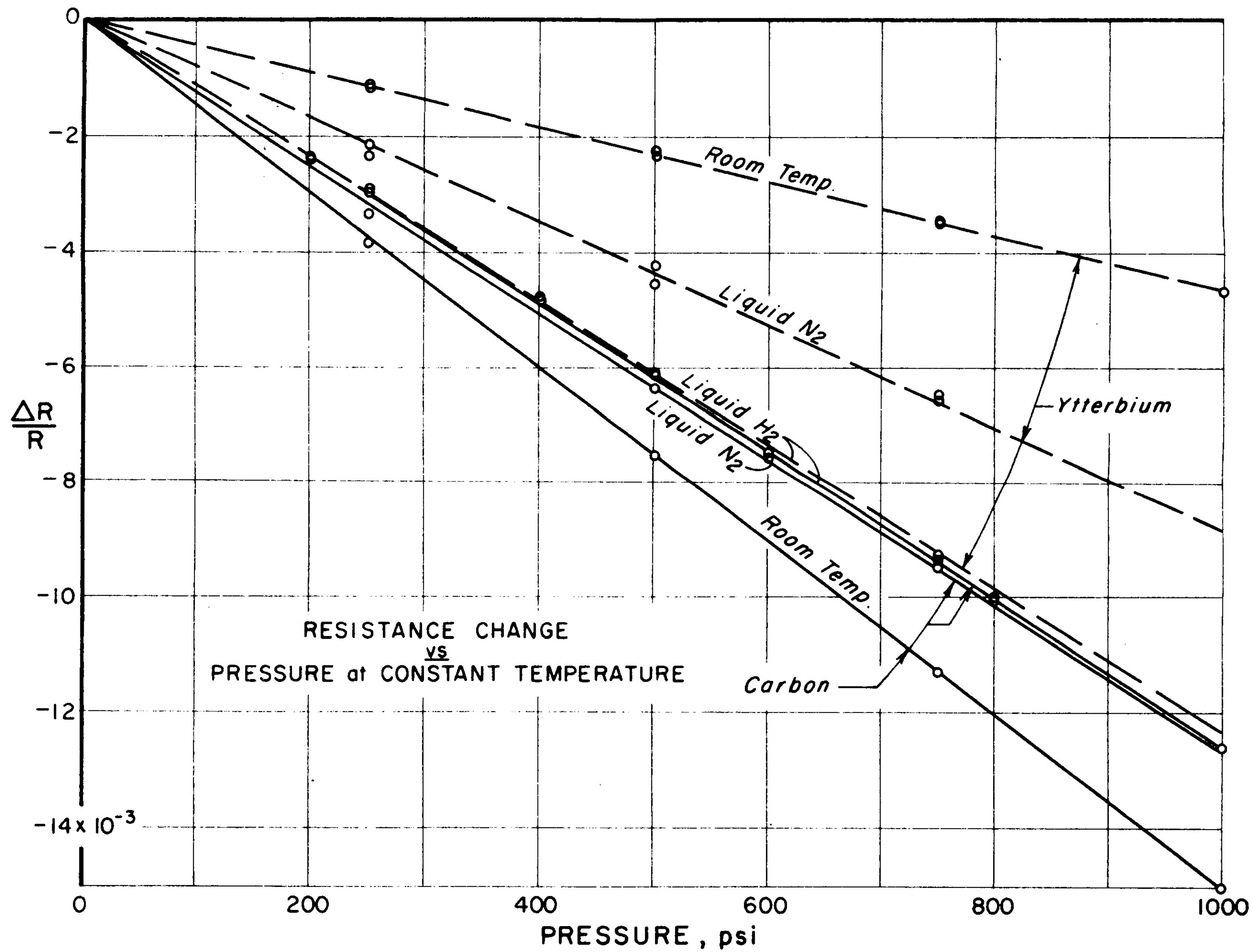

Figure 1. Resistance Change vs. Pressure at Constant Temperature

temperature for the nine cycles was 0.0004 ohms. The average resistance at LH_2 was 0.2717 ohms.

The pressure repeatability was determined by six cycles from 0 to 500 psi at liquid hydrogen temperature. The total change in resistance at 0 psi was 0.0001 ohms and was 0.0002 ohms at 500 psi. The average resistances were measured with a Mueller G2 Bridge with a limit of error of ± 0.0002 ohms using a 4-lead system.

3. Consultation and Advisory Services

3.0 General Comments

Consultation and advisory services in the general field of cryogenic engineering have continued in several NASA program areas: Centaur (funded separately), Rover, and NERVA.

3.1 Centaur Program - Robert W. Arnett

Frequent contact with NASA-Lewis Research Center personnel via telephone has been continued. A trip to General Dynamics/Convair, San Diego was made at the end of this reporting period.

3.1.1 Stratification and Pressurization

Manual calculations for check-out purposes are continuing. Certain program revisions have been accomplished as a result of check points to date. Unexpected behavior of some of the boundary layer functions has been discovered and efforts are underway to take care of this problem.

3.1.2 Flight Data Analysis

Reduction of tape data to graphical form has been delayed due to late arrival of down-range tapes. Preparation for handling data tapes from the upcoming AC-9 flight is being completed.

3.2 Rover Program - Alan F. Schmidt

Information required to resolve several insulation and valve problems at the Nuclear Rocket Development Station was transmitted to the CMF-9 group at Los Alamos.

3.3 NERVA Program - Alan F. Schmidt

A meeting with personnel from General Dynamics, Aerojet-General, and Westinghouse Astronuclear was attended in Fort Worth, Texas on July 6 for the purpose of (1) reviewing problems and status of the thermal conductivity and para-to-ortho hydrogen conversion programs at the Nuclear Aerospace Reactor Facility, and (2) making recommendations involving design improvements for future tests. An outline memorandum covering these discussions and subsequent recommendations was prepared for submission to the Space Nuclear Propulsion Office-Cleveland. Informal telephone and letter reports on the subject also were provided SNPO by NBS.

At various times throughout the quarter, information was furnished SNPO-Cleveland, and -Germantown, on the topics: phase-equilibrium in the hydrogen-methane system; electrolytic hydrogen moisture monitors; and cryogenic helium pressurized storage for space flight application.

The NBS-Cryogenics Division scope of research activity for the next NASA R-45 contract year also was defined during this period.

4. Cryogenic Flow Processes

4.0 General Comments

Personnel contributing to the project during the present reporting period were J. A. Brennan, W. G. Steward, and E. G. Brentari.

4.1 Analytical

The cooldown computer program described in Progress Report #20 has run long enough to produce very reasonable results for one surge. Some of the problems which have been encountered are as follows:

1) Difficulty in handling "wild" pressures and velocities resulting from slightly erroneous trial values of inlet flow rate. Means had to be devised to detect errors such as negative absolute pressures, etc. and remedy them immediately since they would cause the computation to blow up before the normal error detection and correction routines could be reached.

2) It became apparent that a feedback of final computed temperature into the energy equation of gas elements was necessary. Otherwise gas temperatures sometimes exceeded the wall temperature. (Gas temperatures momentarily exceeding the wall temperature are not impossible, however, when rapid pressurization occurs.) This feedback proved to be more difficult than anticipated but was finally accomplished.

3) A more accurate density and specific heat became necessary; therefore, W. J. Hall's TABCODE for these properties as a function of pressure and temperature was installed.

4) Fluid segments which started at very small size eventually became excessively long by the time they reached the warm gas stage. This required subdividing these segments and interpolating to get the conditions at the mid points. Special treatment was necessary for segments which made the transition from two phase to gas.

5) After a large number of segments entered the pipe, the downstream conditions become hypersensitive to inlet flow rate. A tolerance as low as 0.001 percent on inlet flow rate was not low enough to bring convergence. Several methods of handling this hypersensitivity were tried with only partial success. At present a rather extensive revision in the flow correction scheme is being perfected. It shows promise of overcoming the problem.

4.2 Experimental

Experimental work continued this period with subcooled liquid nitrogen tests. Cooldown experiments were run with four different line lengths and four line end restrictions at three driving pressures. Line lengths tested were 200 ft., 150 ft., 82 ft., and 25 ft.

The end restrictions were simple, thick-plate orifices: 0.438 in., 0.337 in., and 0.249 in. diameter and 0.122 in. thick with no relief. In addition to tests with these end restrictions, similar tests were also run with no end restriction.

Since testing was just completed at the end of this reporting period, results will be included in the next progress report.

5. Liquid-Solid Hydrogen Studies

5.0 General Comments

Personnel contributing to the project during the present reporting period were: D. E. Daney, D. B. Mann, and D. B. Chelton.

5.1 Project Objectives - Task 3

The objectives of the program remain unchanged. They have been presented previously in section 5.1 of NBS Report 9248, Twenty-Second Progress Report to National Aeronautics and Space Administration on Cryogenic Research and Development for Period Ending June 30, 1966.

5.2 Project Status

The construction of the apparatus has been completed to the point that preliminary runs with liquid nitrogen are being made. The dewar assembly, together with its associated piping and control panel, is finished. The system has been checked with a mass spectrometer leak detector and found to be leak free. Two electrically-actuated timers will be provided in the apparatus, one for automatic slush production by the freeze-thaw process, and one to synchronize the camera shutter with the thermal radiation shield shutters. The innermost dewar, which has a stainless steel-to-pyrex joint near its top, has been successfully tested under pressure at liquid nitrogen temperatures.

In order to check for optical distortion in the transparent portion of the dewars, photographs were taken of a grid placed in the innermost dewar. All the dewars were filled with liquid nitrogen in order to approximate the conditions under which the photographic studies of hydrogen slush will be made. No significant distortion was observed.

At present, the dewar system is being reassembled following the replacement of the test grid by a movable platform which will hold the solid hydrogen particles in position for photography.

More liquid nitrogen runs are planned in the immediate future. As soon as the system is thoroughly checked out and the photographic techniques are perfected, liquid hydrogen runs will be started.

5.3 Future Plans

Current funding of this project by SNPO will terminate November 1, 1966. The project will be continued without interruption by funding from the NASA-MSFC on Slush Hydrogen Fluid Characterization and Instrumentation Analysis.

6. Thermal Conductivity of Solids

6.0 General Comments

Personnel contributing during this reporting period were D. H. Weitzel, R. L. Powell, and L. L. Sparks. In addition, J. G. Hust has begun to phase into the program in order to assume project leader responsibility when data acquisition begins.

6.1 Program Status

The mechanical system consisting of cryostat, pumps, and transfer line has been assembled, and the cryostat cooled three times to liquid helium temperature. There were no mechanical failures and no leaks in the vacuum system.

The instrument panel rack is complete, with all wiring from the terminal box to the instruments and switches as well as wiring between instruments and switches, complete and double checked. A detailed wiring diagram of this part of the system is complete.

A system for calibration of platinum resistance thermometers in the liquid nitrogen, liquid hydrogen, and liquid helium ranges has been assembled and tested. It will be used to calibrate a PRT for the thermocouple reference block in our apparatus. A calibrated germanium resistance thermometer for double checking the warm end of the thermal conductivity samples is on hand. The chromel wire for our thermocouples has been calibrated and checked for homogeneity. This has also been done for the copper lead-out wire and will be done for the gold-iron thermocouple wire.

The internal fine wiring of the sample holder, tempering system, and two temperature control systems (floating sink and tempering shell) is about 50 percent complete. We should be ready for final checking of the electrical system and beginning of data acquisition during the next reporting period. Mathematical work on data reduction methods and writing of necessary computer programs is in progress.